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SECRET

THE ANALYSIS OF RADARS AS A FUNCTION OF PHOTOGRAPHIC GROUND RESOLUTION

DDR-DUPE

25X1
25X1

SECRET

THE ANALYSIS OF RADARS AS A FUNCTION OF PHOTOGRAPHIC GROUND RESOLUTION

25X1

Technical Report 723-11

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ACKNOWLEDGMENTS

We sincerely appreciate the cooperation and help we received from the photointerpreters and radar analysts who participated in this study.

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INTRODUCTION

In a previous study[1] it was concluded that,

> "In the analysis of missile sites[2] using aerial reconnaissance photography, most, if not all, of the significant intelligence information can be obtained [redacted] ground-resolution photography. 25X1
> Ground resolutions of [redacted] provide little, if any, additional significant intelligence information regarding this class of targets." 25X1

In the discussion section of the report of the missile-site study, the conclusion was qualified in this way,

> "...it must be emphasized that *only missile and missile-related sites were used as targets in this study.* Had electronic facilities or tactical targets been used, the results may have been different. With such targets, *even* [redacted] *ground-resolution photography may not have yielded all of the intelligence information that could be obtained from aerial photography.* The implication is obvious; a similar study must be done with a different class of targets." 25X1

In other words, if the class of targets chosen for study were one characterized by finer detail, then ground resolutions of [redacted] might have yielded significantly more information than obtained with [redacted] ground-resolution photography. 25X1 25X1

[redacted] 25X1

[2] As suggested by the PIs who participated in the study, this phrase should probably read, "...the analysis of domestic, offensive missile sites...."

Mobile radars are targets with considerably finer detail than missile sites. So this study was of the effects of photographic ground resolution on the interpretation and analysis of mobile radar targets.

The practical significance of this and the previous research is perhaps obvious but may warrant repeating. Modern aerial reconnaissance systems are enormously expensive, and obtaining better ground resolutions means even greater expense. Therefore, it is important to learn *what*, if any, additional information will be provided to the intelligence community by obtaining better, more expensive, resolutions.

Though it may never be possible to determine the *value* of such additional information, it is quite possible to determine the minimum resolution required, for different classes of targets, to maximize the amount of *significant* information obtainable by interpretation and analysis. If a point can be found where improved ground resolution provides no additional significant information, then the required ground resolution for aerial reconnaissance systems can be specified.

METHOD

The method was similar to that used in the missile-site study. In brief, an effort was made to simulate operational photographic intelligence practices.

Positive transparencies were prepared to six specified ground resolutions. Two PIs independently read out the transparencies, and each prepared an annotated sketch on an acetate overlay placed over paper-print enlargements of the transparencies. Each pair of PIs then worked together to produce an annotated sketch representing the consensus of their interpretations.

The positive transparencies, annotated sketches, and enlargements were delivered to experienced radar engineers who were knowledgeable about radar design but were not familiar with the radars used in the study. From these materials, the radar engineers prepared a report on each radar at each of the six ground resolutions.

The Radars

During the planning phase of the study, an effort was made to obtain aerial photographs of *real* radar sites having ground resolutions that ranged from a "poor" resolution to a best resolution [redacted] Adequate photographs were not available, so models of nine Sino-Soviet bloc radars were used as targets. Table 1 shows the radars and their functions. 25X1

Intelligence analysts compared preliminary photographs of the models with engineering drawings of the radars and found that at high photographic resolutions the fidelity of only two of the models was inadequate. These two models were modified before the final photographs were prepared.

TABLE 1

THE RADAR TARGETS

TARGET NUMBER	NAME	FUNCTION
1.	STONE CAKE	(HEIGHT FINDER)
2.	FAN SONG (CHINESE VARIENT)	(MISSILE FIRE-CONTROL)
3.	LONG TALK	(GCA)
4.	SPOON REST A	(ACQUISITION)
5.	MOON CONE	(EARLY WARNING)
6.	SHIP WHEEL	(FIRE-CONTROL)
7.	FAN SONG E	(MISSILE FIRE-CONTROL)
8.	BARLOCK	(EARLY WARNING)
9.	SPONGE CAKE	(HEIGHT FINDER)

The Photographs

The models were mounted on a board covered with dark brown wrapping paper and photographed outdoors with the board in a vertical position. In bright sunlight the shadows produced were too pronounced, so the photographs were retaken in hazy sunlight using a secondary light source.

Six ground resolutions were studied: [redacted] 25X1

[redacted] This range of resolution was selected to 25X1
include the resolutions of today's better reconnaissance systems and those of proposed future systems.

Preliminary photographs were taken at different distances from the models, making it possible to compute the resolving power of the film-lens system as a function of distance. From these computations, the distances required to achieve the six selected resolutions were determined and used in making the final photographs.

A pair of final photographs was then taken at each distance, one from 10° to the left of the nadir and one from 10° to the right, to provide stereoscopic pairs with a convergence angle of 20°.[3]

The camera was a 35-mm Kodak Retina 2C with a focal length of 50-mm. Shutter speed was 1/125 sec., and the aperture setting was f/5.6. Kodak Panatomic-X film was used. The transparencies were processed with DuPont 228R duplicating stock.

The scales of the negatives varied from approximately 1:1680 for the highest resolution to approximately 1:36,000 for the lowest. In making the positive transparencies these scale differences were minimized as much as possible without altering the ground resolutions.

Table 2 shows the spatial frequencies, ground resolutions, and scales of the positive transparencies used in the study.

Note that the ground resolutions actually obtained differed slightly from those selected for the study but these differences were considered insignificant. The spatial frequencies given in the table were based upon resolution readings of a three-bar target.

25X1

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TABLE 2

DESCRIPTION OF THE POSITIVE TRANSPARENCIES

25X1

RESOLUTION	SPATIAL FREQUENCY (LINES/MILLIMETER)		SCALE
A	72.0		1/1,800
B	66.0		1/3,600
C	66.0		1/7,200
D	33.3		1/7,200
E	16.3		1/7,200
F	10.0		1/7,200

Subjects

Two types of experimental subjects were used, photo-interpreters (PIs) from the Center and radar engineers (REs). The REs played the role of intelligence analysts. Professional radar intelligence analysts were not used because their intimate familiarity with the radars used as targets might have biased the results.

Six PIs participated in the study. All were specialists in the interpretation of photographs of radars and none had fewer than four years of professional experience in the interpretation of electronic facilities.

Four REs were used in the study. At the time the study was conducted, all were employed in private industry in the field of radar research and development, and all were serving at the time as analysts for OSI.

The Procedure

The six PIs were divided into three teams of two men each. Each team was formed in such a way that the skills and experience of one member complemented those of the other. For example, offensive radar specialists were teamed with defensive radar specialists.

Each team was assigned the task of reading-out three of the nine radar targets at all six resolutions; each of a set of three was a different type of radar. Team one was assigned targets 1 through 3; team two, targets 4 through 6; and team three, targets 7 through 9.

The PIs of each team began by working independently. They analyzed one radar at a time in steps from [redacted], the 25X1
poorest resolution, to [redacted] the best resolution. 25X1

After preparing the independent read-outs, each team discussed its findings and prepared composite read-outs, and annotated sketches of the radars. To control scale at each ground resolution, each team prepared its sketches on tracing paper placed over a paper-print enlargement of one of each stereo-pair. The enlargement factors used in making these paper prints were those that resulted in prints of the maximum dimensions possible without degradation of photographic coherence. The spatial frequencies of these enlargements varied between 3.0 lines/mm and 3.6 lines/mm.

The PIs used stereoscopes, at any desired magnification, in reading out the positive transparencies. They also used a guide prepared by professional radar intelligence analysts, that described the information the analysts wanted about each radar. The guide served as an Essential Elements of Information (EEI) type of document (see Appendix A, "Basic Radar Requirements").

The positive transparencies, the paper-print enlargements, and the annotated sketches prepared by the PIs were delivered to the REs for analysis. As did the PIs, the REs worked side-by-side in teams of two and produced joint analyses. Each had a copy of the positive transparencies and a stereoscope. They examined the PI read-outs as well as the transparencies in making their analyses and, for guidance, they used a checklist that they had prepared from the EEI (see Appendix B, "Radar Response Checklist").

The REs first analyzed all nine read-outs (one for each radar) at the poorest resolution, [redacted] They then proceeded to the next best resolution, and so on until they had analyzed all nine targets at each of the six resolutions. 25X1

The REs produced an enormous amount of information about the targets, and for the purposes of this report it was necessary to develop summary statements of relevant information for each question, target, and resolution. The summary statements prepared by the authors were reviewed by an experienced radar physicist for accuracy. The final

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summary statements are presented in the tables in the Results section of the report.

RESULTS

The results of the study were complex and difficult to interpret and summarize unambiguously. For that reason, the detailed tables that follow in this section were prepared so that the reader could make his own interpretation and summary. Professional analysts in the intelligence community are perhaps best qualified to make judgments concerning the significance of the information produced at each resolution.

However, the authors and some of their engineer colleagues made an effort to summarize the information produced by the REs. For each radar target and each resolution, the responses to each question were compared with the available ground truth. If the response at a better resolution contained more detailed information, partial but correct responses made at poorer resolutions were considered *incomplete*. When ground truth was not available, the response was considered *complete* if no additional significant information was added at better resolutions. The results of the analysis are shown in Table 3.

As can be seen from Table 3, complete answers were given for all nine radar targets at a [redacted] ground resolution to these 25X1 questions:

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TABLE 3

THE NUMBER OF TARGETS FOR WHICH
COMPLETE RESPONSES WERE OBTAINED
BY QUESTION AND GROUND RESOLUTION

25X1

QUESTION							
Number and Type of Vans?		9	-	-	-	-	-
Fixed or Mobile?		9	-	-	-	-	-
Number of Antenna(s)?		4	6	7	9	-	-
Type of Antenna(s)?		7	8	9	-	-	-
Mounting of Antenna(s)?		7	8	9	-	-	-
Frequency of Antenna(s)?		5	5	6*	-	-	-
Horizontal Sector Limits?		9	-	-	-	-	-
Vertical Sector Limits?		4	-	-	-	-	-
Beam Patterns, Horizontal?		7	7	8	-	-	-
Beam Patterns, Vertical?		8	-	-	-	-	-
**Waveguides?		2	4	6	7	-	-
**Feeder Lines?		2	4	8	-	-	-
Function?		9	-	-	-	-	-
Cumulative Complete Responses		82	90	101	104	104	104
Percent of Possible Complete Responses	(115)	71%	78%	88%	90%	90%	90%

*This number indicates that for three targets complete responses were not obtained at any resolution.

**For one radar these questions were not appropriate.

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Number and type of vans?
Fixed or mobile?
Horizontal sector limits?
Function?

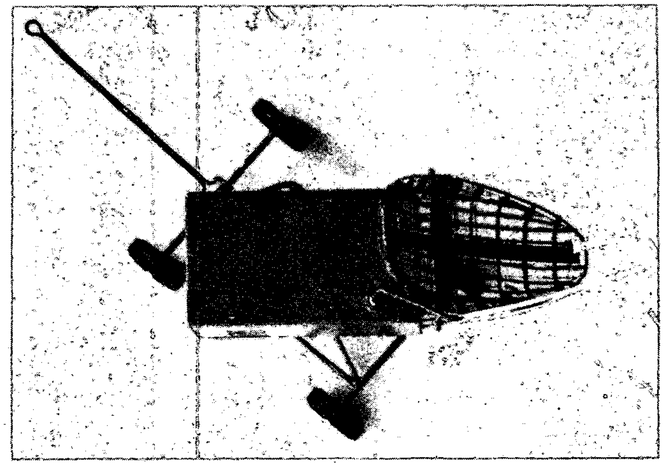
Some questions were not completely answered for all radars until [redacted] ground resolution photography was available. 25X1 And some questions were not completely answered for all radars at the best resolution. Note that some of the latter questions such as, Frequency of Antennas?, would probably be more appropriately asked of an *elint* system.

The number of possible complete responses was 115 (nine targets times 13 questions minus two questions inappropriate for one target). Note that there was an increase in the number of complete responses from a ground resolution [redacted] 25X1 [redacted] the difference between [redacted] being small, but there 25X1 was no difference among [redacted] 25X1

In the tables following (T1 through T9), the areas of gray and the notation "same as" indicate that the REs either added no additional information or added insignificant information as compared to the information they had presented at poorer ground resolutions.

Target Number 1

STONE CAKE



No. & Type of Vans

One rotating van with antenna plus two trucks

Fixed or Mobile

Mobile

No. of Antennas

One

Type of Antennas

Nodding dish

Mounting of Antennas

On end of van

Frequency of Antennas

2578-2666 MHz

Horizontal Sector Limits

360° van rotation

Vertical Sector Limits

0-30°

Beam Patterns--Horizontal

3.7° beam width, horizontal polarization

Beam Patterns--Vertical

1.4° (est)

Wave Guides

Yes--horn feed

Feeder Lines

Not specified

Function

Height finding

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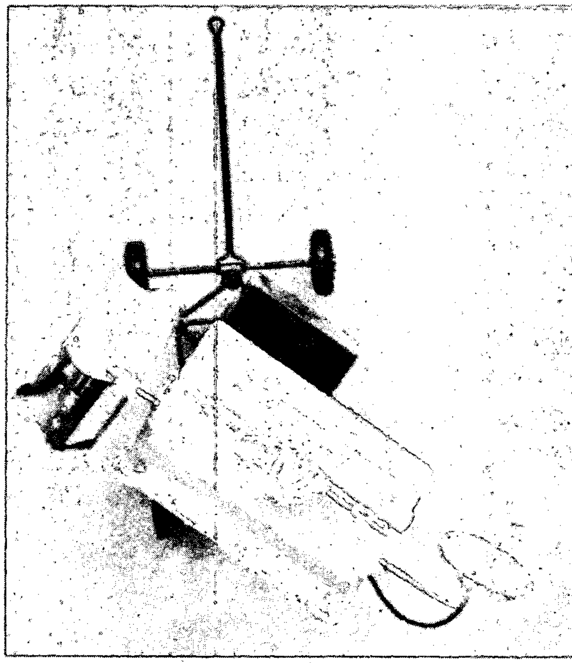
Target Number 2

FAN SONG A



No. & Type of Vans

One

Fixed or Mobile

Mobile

No. of Antennas

Four

Type of Antennas

One horiz. trough
One vert. trough
Two [redacted] dishes

Mounting of Antennas

One [redacted] dish over horiz. trough; [redacted] dish at end on arm; vert. trough at end

Frequency of Antennas

Horiz. trough 2940-3000 MHz
Vert. trough 3000-3060 MHz

Horizontal Sector Limits

Vert. trough 17°-20°
Van rotates 360°

Vertical Sector Limits

Horiz. trough 17°-20°

Beam Patterns--Horizontal

Horiz. trough 2°
Vert. trough 10°
Dishes 10°-15°

Beam Patterns--Vertical 25X1

Horiz. trough 10°
Vert. trough 2°
Dishes 10°-15° 25X1

Wave Guides 25X1

No specified

Feeder Lines

Not specified

Function

Missile guidance and tracking

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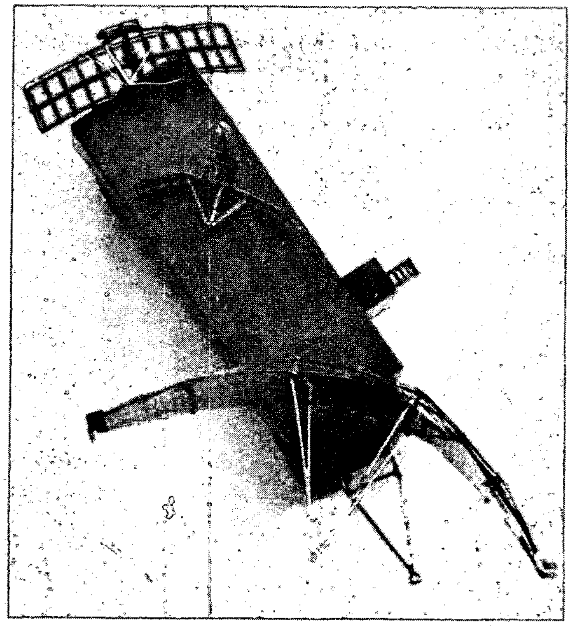
Target Number 3

LONGTALK



No. & Type of Vans

One van (enclosed)

Fixed or Mobile

Mobile

No. of Antennas

Four

Type of Antennas

Curved reflectors--one each large, medium and small (one small vert., others horiz.)

Mounting of Antennas

Large and medium reflectors at ends on top of van; small vert. above small horiz.; off-center of van top

Frequency of Antennas

Large - 820-890 MHz
Medium - 9050-9500 MHz (pos.)
Small - not specified

Horizontal Sector Limits

Large - 360°
Small and medium not specified

Vertical Sector Limits

Not specified

Beam Patterns--Horizontal

Large - 2.2°
Medium - 0.64°
Small - 2.1°

Beam Patterns--Vertical

Large - not specified
Medium - 0.45°
Small - 4.1°

Wave Guides

Not specified

Feeder Lines

Not specified

Function

GCA

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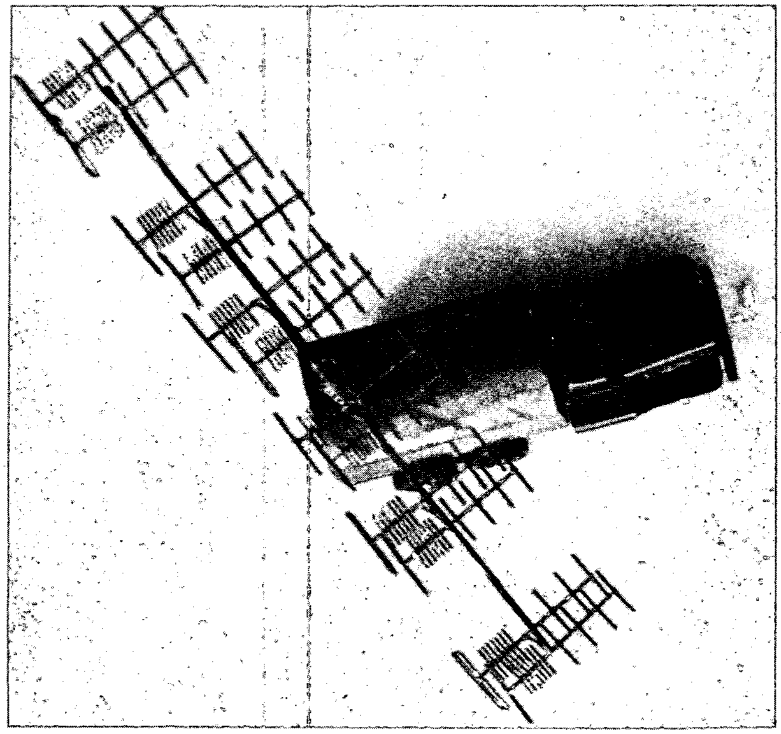
Target Number 4

SPOON REST A



No. & Type of Vans

One covered truck for antenna mounting;
One van-truck with equipment

Fixed or Mobile

Mobile

No. of Antennas

Twelve

Type of Antennas

Yagi

Mounting of Antennas

Two horiz. rows of 6 each on boom--in turn on lattice mast

Frequency of Antennas

152-160 MHz

Horizontal Sector Limits

360° rotation

Vertical Sector Limits

Tiltable above and below horizontal

Beam Patterns--Horizontal

5°-10°

Beam Patterns--Vertical

Not specified

Wave Guides

Not specified

Feeder Lines

Not specified

Function

Early warning and SAM acquisition

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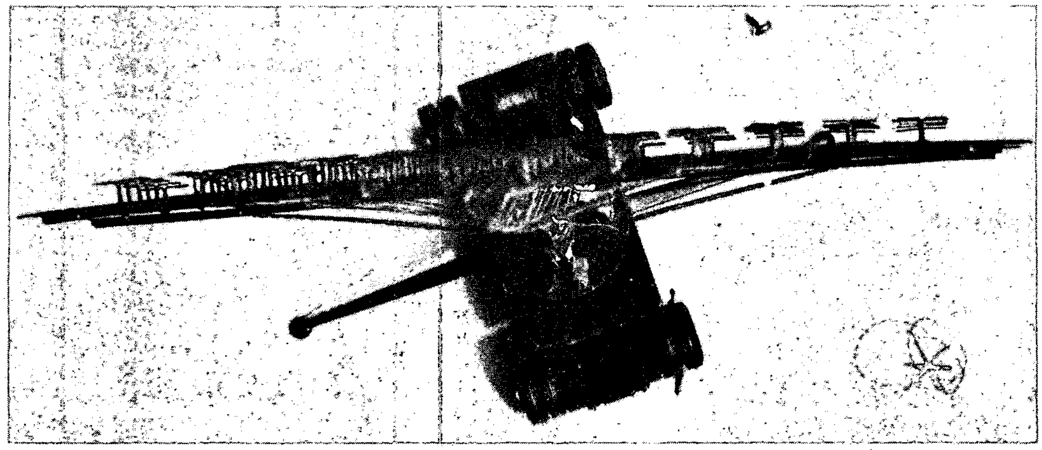
Target Number 5

MOON CONE



No. & Type of Vans

Type SCR-270
open trailer

Fixed or Mobile

Mobile antenna (fixed installation use--support equipment in small building)

No. of Antennas

Three

Type of Antennas

Vertically stacked mattresses
Large bottom with 6 horiz. rows of 8-12 dipoles, smaller middle with 4 horiz. rows of 8 dipoles, smallest top with 4 horiz. rows of 4 dipoles

Mounting of Antennas

Mast on pedestal (open frame work)

Frequency of Antennas

145-161 MHz

Horizontal Sector Limits

360° continuous

Vertical Sector Limits

Fixed

Beam Patterns--Horizontal

Horiz. polarization
8°-12° beam width

Beam Patterns--Vertical

Two distinct lobes
Lower lobe MRA 3° above horiz.
Upper lobe MRA 8° above horiz.

Wave Guides

None

Feeder Lines

Type not specified

Function

Early warning

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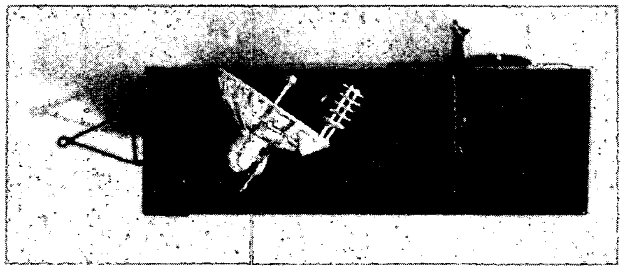
Target Number 6

FIREWHEEL



No. & Type of Vans

One van (enclosed)

Fixed or Mobile

Mobile

No. of Antennas

Three

Type of Antennas

One 3 meter parabolic dish
Two helical antennas

Mounting of Antennas

Dish on top of and at end of van, helical antennas mounted on lower right side of the dish

Frequency of Antennas

2695-3020 dish
Helices not specified part of FOILTWO system

Horizontal Sector Limits

360° rotation

Vertical Sector Limits

Not specified

Beam Patterns--Horizontal

2.7° circular and spiral

Beam Patterns--Vertical

2.7° circular and spiral

Wave Guides

Not specified

Feeder Lines

Not specified;
Dipole fed

Function

Fire control

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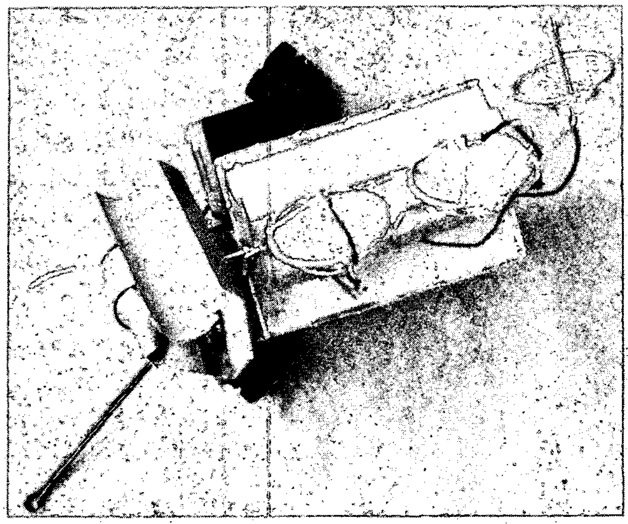
Target Number 7

FAN SONG E



No. & Type of Vans

One

Fixed or Mobile

Mobile

No. of Antennas

Five

Type of Antennas

One horiz. trough
One vert. trough
Two [redacted] dishes
One [redacted]. dish

Mounting of Antennas

Two [redacted] dishes over
horiz. trough, [redacted]
dish at end on arm,
vert. trough at end

Frequency of Antennas

Horiz. trough 4910-4990 MHz
Vert. trough 5010-5090 MHz
[redacted] dish 723-802 MHz
[redacted] dishes not specified

Horizontal Sector Limits

Vert. trough 17°-20°
Van rotates 360°

Vertical Sector Limits

Horiz. trough 17°-20°

Beam Patterns--Horizontal

Vert. trough 7.5°-10°
Horiz. trough 1.2°
[redacted] dish 25X1
14° circular

Beam Patterns--Vertical 25X1

Vert. trough 1.2°
Horiz. trough 7.5°-10°
[redacted] dish 25X1
14° circular 25X1
25X1

Wave Guides

Not specified

Feeder Lines

Not specified
25X1

Function 25X1

Missile guidance and
tracking

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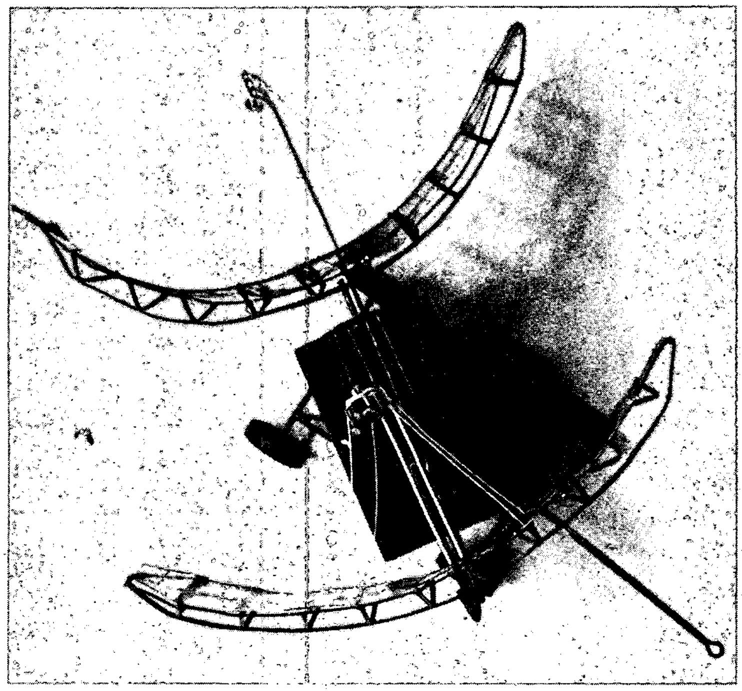
Target Number 8

BARLOCK



No. & Type of Vans

One

Fixed or Mobile

Mobile

No. of Antennas

Two

Type of Antennas

Truncated parabolic
mesh reflectors

Mounting of Antennas

Horiz. fore and aft

Frequency of Antennas

2700-3119 MHz

Horizontal Sector Limits

360° van rotation

Vertical Sector Limits

Upper antenna 5.5° up, 7° down
Lower antenna 4° up, 5.5° down

Beam Patterns--Horizontal

0.8°-1.8° (frequency dependent)

Beam Patterns--Vertical

1.4°-11.4° (frequency dependent)

Wave Guides

Lower antenna fed by 4 S-band guides, horn terminated. Upper antenna fed by 2 S-band guides, one terminated by dual or split horn; other terminates in 8 dipoles

Feeder Lines

Not specified

Function

Early warning

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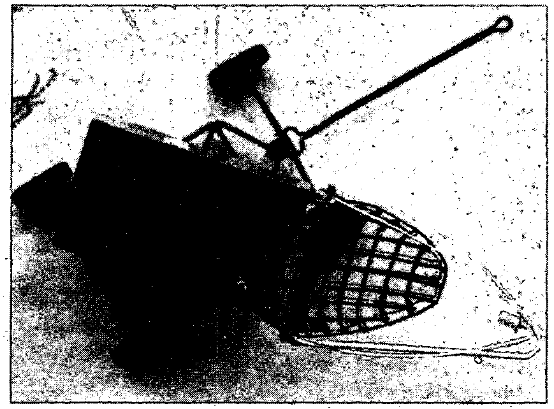
Target Number 9

SPONGE CAKE



No. & Type of Vans

One rotating van with antenna plus two trucks

Fixed or Mobile

Mobile

No. of Antennas

One

Type of Antennas

Similar to STONE CAKE but lighter--nodding dish

Mounting of Antennas

On end of van

Frequency of Antennas

2689-2763, 2796-2856 MHz

Horizontal Sector Limits

360° van rotation

Vertical Sector Limits

0-30°

Beam Patterns--Horizontal

3.7° same as STONE CAKE

Beam Patterns--Vertical

1.4° (est) same as STONE CAKE

Wave Guides

Yes--horn feed

Feeder Lines

Not specified

Function

Height finding

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DISCUSSION

The purpose of the study was to attempt to determine what information could be learned about mobile radar targets as a function of the ground resolution of aerial photography. Additional information *was* obtained as resolution improved, but the question is: How valuable is the additional information to our national security in light of the significant, additional system costs? The authors have left the burden of answering that question to the reader.

Precise measures are required to infer electronic characteristics of radars of this type. It was not entirely possible to determine the accuracy of the models for the purposes of a mensuration study. Consequently this study was limited to "interpretation" without measures. However, the REs did make measurements and, at the better resolutions, model inaccuracies could have led to measurements that in turn led to erroneous inferences about electronic characteristics.

It was not possible in analyzing the data to distinguish inferences from what was actually seen. The PIs produced annotated overlays so their responses probably reflected what they saw. But the REs, in some instances, may have inferred the presence of some features of the radars on the basis of their knowledge of radar functions.

The "open-end" format of the questions asked the PIs and REs made very difficult the task of reducing the enormous amount of data produced in the study. The amount of data wasn't the only difficulty: differences in terminology also had to be resolved. If a similar study were to be done with a different class of targets, the experimenter should consider the possibility of adding greater structure to the response requirements, perhaps a structure similar to a multiple-choice test.

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APPENDIX A

BASIC RADAR REQUIREMENTS

Used by the PIs in preparing their annotated sketch read-outs

Generally speaking, the intelligence community wants the answers to two fundamental questions regarding the radars of potential enemies:

1. *What is its function?* For example, fire control, missile guidance, early warning, etc. The answer to the question is generally inferred by the intelligence analysts from the configuration and general description of the radar, from its location, from its association with or relation to other equipment, from the number of apertures or elements, from descriptions of the feeds, and from gross measurements.

2. *What are its basic technical and performance characteristics?* For example, antenna pattern and gain, antenna scanning modes and volume of coverage. The answers to this question are inferred by the intelligence analysts from numerous factors.

   a. Description and size of the antenna or antennas (bedspring, yagi, parabolic reflector--mesh or solid--etc.).

b. Description, size, and orientation of feed mechanisms (horn, dipole, line source, scanner, etc.; f/D ratio, feed tilt, etc.).

c. Description and dimensions of r.f. lines (waveguide, coax).

d. Description of site.

e. Identification of any appendages related to beam shaping.

f. Mechanical connection of antenna to its mount (circular scan, vertical sector, horizontal sector, etc.).

g. Mechanical relationship between multiple antennas on a single mount. (For example, are they capable of independent motion?)

h. Limits of mechanical motion. (For example, sector limits of a nodding height finder.)

i. Detailed description of any scanning feed mechanism, including r.f. connections, electrical connections, mechanical drives, etc.

j. Identification and dimensions of feed aperture.

k. Identification of type of scanner.

The intelligence analyst would also like to know basic signal characteristics, such as transmission frequency, PRF, scan rate, etc., which may not be available from reconnaissance photography.

From all of this information, the analysts try to infer the capabilities, limitations, and vulnerabilities of a radar.

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APPENDIX B

RADAR RESPONSE CHECKLIST

Used by the REs in
analyzing the targets

1. *Type of van?*
2. *Fixed or mobile?*
3. *Number of antennas?*
4. *Type of antennas?*
5. *Mounting of antennas?*
6. *Size of antennas?*
7. *Frequency of antennas?*
8. *Horizontal sector limits?*
9. *Vertical sector limits?*
10. *Beam patterns, horizontal?*
11. *Beam patterns, vertical?*
12. *Wave guides?*
13. *Feeder lines?*
14. *Function?*
15. *Comments*
16. *Significance*

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